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[Document Name] Specification

[Title of the Invention] Compressor Bearing

[Scope of Claims for Patent]

[Claim 1] A compressor bearing used for a compressor body and a pulley mechanism transmitting a driving force to said compressor body, wherein at least one member of an outer ring, an inner ring and a plurality of rolling elements included in said compressor bearing has a hydrogen content of at most 0.5 ppm.

[Claim 2] A compressor bearing used for a compressor body and a pulley mechanism transmitting a driving force to said compressor body, wherein at least one member of an outer ring, an inner ring and a plurality of rolling elements included in said compressor bearing has an austenite grain with a grain size number falling within a range exceeding 10.

[Claim 3] A compressor bearing used for a compressor body and a pulley mechanism transmitting a driving force to said compressor body, wherein at least one member of an outer ring, an inner ring and a plurality of rolling elements included in said compressor bearing has a fracture stress value of at least 2650 MPa.

[Claim 4] The compressor bearing according to any of claims 1 to 3, wherein said compressor bearing is a swash plate support bearing rotatably and axially supporting a swash plate and a coupling member of said compressor body.

[Claim 5] The compressor bearing according to any of claims 1 to 3, wherein said compressor bearing is a rotating member/pulley support member bearing rotatably and axially supporting a coupling member of said compressor body and a pulley bearing support member of said pulley mechanism.

[Claim 6] The compressor bearing according to any of claims 1 to 3, wherein said compressor bearing is a main shaft support bearing rotatably and axially supporting a main shaft of said compressor body and a pulley bearing support member of said pulley mechanism.

[Claim 7] The compressor bearing according to any of claims 1 to 3, wherein

said compressor bearing is a pulley support bearing rotatably and axially supporting a pulley and a pulley bearing support member of said pulley mechanism.

[Claim 8] The compressor bearing according to claim 4, wherein said swash plate support bearing is a needle roller thrust bearing.

[Claim 9] The compressor bearing according to claim 5, wherein said rotating member/pulley support member bearing is a needle roller thrust bearing.

[Detailed Description of the Invention]

[Technical Field to Which the Invention Belongs]

The present invention relates to a compressor bearing used for a compressor body and a pulley mechanism transmitting a driving force to the compressor body.

[Prior Art]

To provide a longer rolling contact fatigue life of a rolling bearing incorporated into a compressor with a pulley mechanism (referred to as a compressor bearing hereinafter), a thermal treatment is performed. Conventionally, for example, in quenching the components they are heated in an ambient RX gas with ammonium gas further introduced therein to carbo-nitride their surface layer portion. This carbonitriding process can harden the surface layer portion and generate retained austenite in a microstructure to provide increased rolling contact fatigue life (see Patent Document 1 and Patent Document 2).

[Patent Document 1]

Japanese Patent Laying-Open No. 11-101247

[Patent Document 2]

Japanese Patent Laying-Open No. 8-4774

[Problems to be Solved by the Invention]

The above-mentioned carbonitriding process for the compressor bearing components is a process to diffuse carbon and nitrogen. This requires that the bearing components have to be held at a high temperature for a long period of time.

When bearing components are held at a high temperature for a long time, an

austenite grain is coarsened in size resulting in reduced toughness and thus brittle steel. This leads to a problem of reduced crack strength.

In addition, the coarsened austenite grain results and increased anti-crack strength is hardly obtained. Furthermore, as more austenite is retained, secular dimensional variation rate increases, which is another problem.

The carbonitriding process of diffusing carbon and nitrogen requires that bearing components should be maintained at a high temperature for a long period of time. This results in a coarsened structure and imposes a limitation on increasing a fracture stress value, which corresponds to anti-crack strength.

On the other hand, there are demands on the compressor bearing with a pulley mechanism (1) to secure a long rolling contact fatigue life, (2) to improve anti-crack strength, and (3) restrain an increase in secular dimensional variation rate.

In conventional techniques, to achieve such mechanical characteristics, compositions are adjusted in designing steel alloys. However, a raw material of a special alloy component is hardly available thereby leading to high costs.

A future compressor bearing with a pulley mechanism is requested to have a mechanical characteristic that allows for the use under a higher load and at a higher temperature than the conventional bearings in order to accommodate an environment of a higher load and higher temperature.

Therefore, the above-described compressor bearing needs to be strong and requires (1) a long rolling contact fatigue life, (2) a high anti-crack strength, and (3) dimensional stability enhanced by restraining an increase in secular dimensional variation rate.

The present invention aims to provide a compressor bearing having (1) a long rolling contact fatigue life, (2) a high anti-crack strength, and (3) dimensional stability enhanced by restraining an increase in secular dimensional variation rate.

[Means for Solving the Problems]

Means for solving the problems is a compressor bearing used for a compressor

body and a pulley mechanism transmitting a driving force to the compressor body. At least one member of an outer ring, an inner ring and a plurality of rolling elements included in the compressor bearing has a hydrogen content of at most 0.5 ppm, an austenite grain with a grain size number falling within a range exceeding 10 or a fracture stress value of at least 2650 MPa.

Here, the austenite grain refers a grain austenite after the austenite is transformed in phase through quenching, and refers to a trace thereof after the austenite is transformed into martensite through cooling.

[Embodiments of the Invention]

In a first embodiment of the present invention, as shown in Fig. 1 described hereinlater, compressor bearings 401 to 404 will be described that are used for a compressor body 200 and a pulley mechanism 400 transmitting a driving force to compressor body 200. The compressor bearing is, for example, (a1) a swash plate support bearing 404 rotatably and axially supporting a swash plate 203 and a rotating member 211 of compressor body 200, (a2) a rotating member/pulley support member bearing 401 rotatably and axially supporting rotating member 211 and a pulley bearing support member 418, (a3) a main shaft support bearing 402 rotatably and axially supporting a main shaft 204 and pulley bearing support member 418 or (a4) a pulley support bearing 403 rotatably and axially supporting a pulley 425 and pulley bearing support member 418.

As shown in Figs. 6 to 9 described hereinlater, at least one member of an outer ring 31, an inner ring 32 and a plurality of rolling elements 33 forming at least one bearing of compressor bearings 401 to 404 undergoes heat treatment so that the above described characteristics are obtained. The heat treatment refers to the process as shown in Fig. 2 for example described hereinlater of performing (primary) quenching for a carbonitriding process at temperature T1 and thereafter heating at temperature T2 lower than temperature T1 of the carbonitriding process, and performing (secondary) quenching. As a result, the bearing includes a member having a hydrogen content of at

most 0.5 ppm.

In a second embodiment of the present invention, similarly to the above-described first embodiment, at least one member of outer ring 31, inner ring 32 and a plurality of rolling elements 33 forming at least one bearing of compressor bearings 401 to 404 undergoes heat treatment so that the above-described characteristics are obtained. The heat treatment refers to a process as shown in Fig. 3 for example described hereinlater of performing carbonitriding at temperature T1 to form a carbonitriding layer, thereafter cooling the material to a temperature less than A1 transformation temperature, and subsequently heating it at temperature T2 lower than temperature T1 of the carbonitriding process so as to perform quenching. As a result, the bearing includes a member having a hydrogen content of at most 0.5 ppm.

In a third embodiment of the present invention, similarly to the above-described first embodiment, at least one member of outer ring 31, inner ring 32 and a plurality of rolling elements 33 forming at least one bearing of compressor bearings 401 to 404 undergoes heat treatment so that the above-described characteristics are obtained. The heat treatment refers to a process as shown in Fig. 2 for example described hereinlater of performing (primary) quenching for a carbonitriding process at temperature T1 and thereafter heating to temperature T2 lower than temperature T1 for carbonitriding, and performing (secondary) quenching. As a result, the bearing includes a member having an austenite grain with a grain size number falling within a range exceeding 10.

In a fourth embodiment of the present invention, similarly to the above-described first embodiment, at least one member of outer ring 31, inner ring 32 and a plurality of rolling elements 33 forming at least one bearing of compressor bearings 401 to 404 undergoes heat treatment so that the above-described characteristics are obtained. The heat treatment refers to a process as shown in Fig. 3 for example described hereinlater of performing carbonitriding at temperature T1 to form a carbonitriding layer, thereafter cooling the material to a temperature less than A1 transformation temperature, and subsequently heating it at temperature T2 lower than temperature T1 of the

carbonitriding process so as to perform quenching. As a result, the bearing includes a member having an austenite grain with a grain size number falling within a range exceeding 10.

In a fifth embodiment of the present invention, similarly to the above-described first embodiment, at least one member of outer ring 31, inner ring 32 and a plurality of rolling elements 33 forming at least one bearing of compressor bearings 401 to 404 undergoes heat treatment so that the above-described characteristics are obtained. The heat treatment refers to a process as shown in Fig. 2 for example described hereinlater of performing (primary) quenching for a carbonitriding process at temperature T1, and thereafter heating to temperature T2 lower than temperature T1 for carbonitriding and performing (secondary) quenching. As a result, the bearing includes a member having a fracture stress value of at least 2650 MPa.

In a sixth embodiment of the present invention, similarly to the above-described first embodiment, at least one member of outer ring 31, inner ring 32 and a plurality of rolling elements 33 forming at least one bearing of compressor bearings 401 to 404 undergoes heat treatment so that the above-described characteristics are obtained. The heat treatment refers to a process as shown in Fig. 3 for example described hereinlater of performing carbonitriding at temperature T1 to form a carbonitriding layer, thereafter cooling the material to a temperature less than A1 transformation temperature, and subsequently heating it at temperature T2 lower than temperature T1 of the carbonitriding process so as to perform quenching. As a result, the bearing includes a member having a fracture stress value of at least 2650 MPa.

[Examples]

[1] Compressor

Fig. 1 is a schematic cross-sectional view of a compressor including a pulley mechanism for a single swash plate-type swash plate compressor 200 and a compressor pulley mechanism 400. First of all, referring to Fig. 1, single swash plate-type swash plate compressor 200 of compressors having the pulley mechanism will be described.

In the case of the single swash plate-type swash plate compressor 200, as shown in Fig. 1, between swash plate 203 and a housing 202 and between swash plate 203 and rotating member 211, a multiple-row needle roller thrust bearing 2 is disposed as a support structure receiving a thrust load. In this compressor 200, as main shaft 204 rotates, rotating member 211 rotates, thereby causing swash plate 203 to swing and reciprocate a piston rod 215. Then, a piston 207 coupled to piston rod 215 is reciprocated in a cylinder.

[2] Compressor pulley mechanism

Next, with reference to Fig. 1 described above, a brief description of compressor pulley mechanism 400 will be given.

In Fig. 1, a pulley bearing support member 418 is fixedly screwed to housing 202 of the compressor. Furthermore, a clutch electromagnet 419 is fixedly attached to pulley bearing support member 418. On the other hand, a power transmitting member 424 is fitted to the end of main shaft 204. A pulley 425 is fitted on the outer circumference of pulley support bearing 403.

In this state, by exciting or not exciting clutch electromagnet 419, the rotary driving force of pulley 425 rotated by a driving force (not shown) is transmitted to main shaft 204 to operate the compressor, or the rotary driving force of pulley 425 is not transmitted to main shaft 204 to terminate the operation of the compressor.

[3] Compressor bearing

The compressor bearing is broadly divided into a compressor bearing for use in compressor body 200 and a compressor bearing for use in pulley mechanism 400.

The compressor bearing for use in compressor body 200 is formed of swash plate support bearing 404 rotatably and axially supporting swash plate 203 and rotating member 211, and rotating member/pulley support member bearing 401 rotatably and axially supporting rotating member 211 and pulley bearing support member 418.

The compressor bearing for use in pulley mechanism 400 is formed of main shaft support bearing 402 rotatably and axially supporting main shaft 204 and pulley bearing

support member 418, and pulley support bearing member 403 rotatably and axially supporting pulley 425 and pulley bearing support member 418.

A needle roller thrust bearing shown in Fig. 9 as described later is used for rotating member/pulley support member bearing 401 and for swash plate support bearing 404. A needle roller thrust bearing or a cylindrical roller bearing shown in Fig. 7 as described later is used for main shaft support bearing 402. A deep groove ball bearing shown in Fig. 6 (A) or a multiple-row angular contact ball bearing shown in Fig. 6 (B), as described later, is used for pulley support bearing 403. Alternatively, a four-point contact ball bearing shown in Fig. 8 may be used.

Fig. 6 is a cross-sectional view showing a deep groove ball bearing and a multiple-row angular contact ball bearing. As the bearings shown in the drawing, a ball bearing formed with an outer ring 31, an inner ring 32, a plurality of balls 33 as rolling elements and a retainer 34 is used. Fig. 7 is a cross sectional view showing a cylindrical roller bearing. As the bearing shown in Fig. 7, a cylindrical roller bearing formed with an outer ring 31a, an inner ring 32a, a plurality of balls 33a as rolling elements and a retainer 34a is used. Fig. 8 is a cross sectional view showing a four-point contact ball bearing. As the bearing shown in Fig. 8, a four-point contact ball bearing formed with an outer ring 31a, an inner ring 32b and a plurality of balls 33b as rolling elements and a retainer 34b is used.

Fig. 9 is a cross-sectional view showing a needle roller thrust bearing. In Fig. 9, (A) is a partial perspective cross section enlarging a part of the needle roller bearing, (B) is a plan view of a needle roller 2 taken from (A) of Fig. 9, and (C) is a partial cross section of needle roller 2 and needle roller retainer 34c at a central portion of needle roller 2, along line B1-B1 in (A) of Fig. 9.

The compressor body bearing employs a needle roller thrust bearing having a large roller diameter in order to endure impact from piston 207. The needle roller thrust bearing is structured such that needle roller 2 is in line contact with the railway surface as described later. On the railway surface in line contact with needle roller 2,

the farther from the rotation center of the bearing toward the outer diameter, the greater is the circumferential velocity. Needle rollers 2 of the needle roller thrust bearing in Fig. 9 is divided into an outer diameter-side needle roller 2a and an inner diameter-side needle roller 2b. Needle roller retainer 34c is formed of an upper retainer 3 and a lower retainer 4.

The needle roller thrust bearing as the compressor bearing for use in compressor body 200 does not have an outer ring and an inner ring as with a normal bearing, and therefore a plurality of needle rollers 2 are retained in retainer 34c and rotate in line contact with the railway surface. In swash plate support bearing 404, each of swash plate 203 and rotating member 211 serves as a railway surface. In rotating member/pulley support member bearing 401, each of rotating member 211 and pulley bearing support member 418 serves as a member having a railway surface.

The needle roller thrust bearing has, as shown in Fig. 9, a plurality of needle rollers 2 and needle roller retainer 34c composed of two annular retainers 3 and 4 circumferentially holding these needle rollers 2 at predetermined pitches. These two retainers 3 and 4 have a plurality of rectangular pockets 5 and 6 each having a length longer than a length L of needle roller 2 in the circumferential direction. Roller retaining portions 5a and 6a are formed to protrude in opposite directions at the both edges of pockets 5 and 6. Needle roller 2 is retained such that it is sandwiched in the circumferential direction by retaining portions 5a and 6a.

[4] Heat treatment performed on the compressor bearing

In the following, the heat treatment will be described that is performed in the process of manufacturing the compressor bearing of the invention used for compressor 200 as well as the compressor bearing of the invention used for compressor pulley mechanism 400. In the following, the compressor bearing is referred to as a member of the invention, namely a member to which the invention is directed. In Figs. 2 and 3, (1) "normal quenching" shown in Fig. 2 (B) or Fig. 3 (A) refers to quenching without performing "carbonitriding process" shown in Fig. 2 (A) or Fig. 3 (A). Further, (2)

"primary quenching" in Fig. 2 (A) refers to the first quenching performing heating to a heating temperature T1 for the carbonitriding (hereinafter referred to as carbonitriding process heating temperature) and performing quick cooling by oil quenching. (3) "Secondary quenching" shown in Fig. 2 (B) refers to the second quenching performed after the primary quenching shown in Fig. 2 (A), performing heating to a heating temperature T2 for normal quenching (hereinafter referred to as normal quenching heating temperature) and performing quick cooling by oil quenching.

In contrast, in Fig. 3 (A), after the heating to carbonitriding process temperature T1, the cooling is performed to a temperature lower than A1 transformation temperature. The cooling is not quick cooling by oil quenching between Fig. 2 (A) and Fig. 2 (B) as described above. Therefore, quenching is not performed. Thus, the quenching shown in Fig. 3 is performed only once, and the two quenching processes like (A) "primary quenching" and (B) "secondary quenching" in Fig. 2 are not identified.

Fig. 2 shows a first heat treatment pattern of performing oil quenching after the primary quenching of the member of the invention to a temperature considerably lower than A1 transformation temperature and thereafter performing the secondary quenching.

In Fig. 2, (A) illustrates the primary quenching performing the carbonitriding process by heating to carbonitriding process heating temperature T1 (845°C) and thereafter the oil quenching from carbonitriding process heating temperature T1 so as to perform quenching. In Fig. 2 (B) illustrates the subsequent secondary quenching performing the heating to normal quenching temperature T2 (800°C) lower than above-described carbonitriding process heating temperature T1 (845°C), and thereafter the oil quenching so as to perform quenching. The first heat treatment pattern shown in Fig. 2 (A) and (B) performs the primary quenching using the oil quenching and thereafter the second quenching by heating from the low temperature to normal quenching temperature T2 (800°C) lower than carbonitriding process heating temperature T1 and the oil quenching.

Fig. 3 shows a second heat treatment pattern having similar effects to those of

the above-described first heat treatment pattern, and the second heat treatment pattern performs the heating for the carbonitriding process of the member of the invention, thereafter performs the heating again when the temperature becomes lower than A1 transformation temperature, and thereafter performs oil quenching so as to perform quenching.

The second heat treatment method shown in Fig. 3 cools the member of the invention, while the heating at the carbonitriding process heating temperature is continued, to a temperature (hereinafter referred to as low temperature close to A1 transformation point) which is lower than A1 transformation temperature and considerably higher than the temperature at the start of the heating without cooling to a temperature near the temperature at the start of the heating. After this, the heating is performed again to normal quenching temperature T2 lower than carbonitriding process heating temperature T1 and the oil quenching is performed so as to accomplish quenching.

Therefore, the second heat treatment method shown in Fig. 3 differs from the first heat treatment method shown in Fig. 2 described above in that the member of the invention is heated at carbonitriding process heating temperature T1 to form a carbonitriding layer, and thereafter the member is cooled to the temperature close to the A1 transformation temperature while the heating at carbonitriding process temperature T1 is continued, and subsequently heating is performed at normal quenching temperature T2 lower than carbonitriding process temperature T1, and oil quenching is performed so as to accomplish quenching.

On the contrary, a common feature of the heat treatment method of the first heat treatment pattern and the heat treatment method of the second heat treatment pattern is that the heating is performed for the carbonitriding process and thereafter the temperature is made lower than A1 transformation temperature, and thereafter the heating is performed again and the oil quenching is preformed so as to accomplish quenching.

[5] As to hydrogen content of at most 0.5 ppm

In the following, a heat treatment method will be described of providing a hydrogen content of at most 0.5 ppm of a carbonitriding layer of at least one member of the inner ring, the outer ring and a plurality of rolling elements included in the compressor bearing of the present invention.

The invention of the first embodiment or the second embodiment described above quenches at least one member of the inner ring, outer ring and a plurality of rolling elements in order to perform the carbonitriding process as shown in Fig. 2 or Fig. 3 described above, thereafter makes the temperature lower than A1 transformation temperature, and thereafter performs heating again and oil quenching so as to accomplish quenching. Through the process, the compressor bearing member can have a hydrogen content of the carbonitriding layer of at most 0.5 ppm.

By this heat treatment process, the degree of embrittlement of the steel due to hydrogen can be lessened. If the hydrogen content exceeds 0.5 ppm, the crack strength decreases, resulting in inappropriateness for use in a portion subjected to severe load. Although a lower hydrogen content is desirable, a long-time heating is necessary for decreasing the hydrogen content to less than 0.3 ppm, and accordingly the austenite grain size is coarsened, resulting in undesired reduction of toughness and cancellation of the effect of reducing the hydrogen content in the first or second embodiment. Therefore, it is necessary that the hydrogen content is in the range of 0.3 ppm to 0.5 ppm which is preferably the range of 0.35 ppm to 0.45 ppm.

In measuring the above hydrogen content, the content of diffusible hydrogen is not measured and only the non-diffusible hydrogen released from the steel at a predetermined temperature or higher is measured. Diffusible hydrogen in a sample of a small size is released from the sample to be scattered even at room temperature, and therefore the diffusible hydrogen is not measured. Non-diffusible hydrogen is trapped in any defect in the steel and only released from the sample at a predetermined heating temperature or higher. Even if what is to be measured is limited to the content of non-

diffusible hydrogen, the hydrogen content varies depending on the method of measurement. The above-mentioned range of the hydrogen content is determined by thermal conductimetry. The measurement is taken by means of a LECO DH-103 hydrogen determinator or like measuring device.

[6] As to the average grain size of 6 μm of the austenite grain

In the following, a description will be given of a heat treatment method providing an average grain size of at most 6 μm of the austenite grain of the carbonitriding layer of at least one member of the outer ring, inner ring and a plurality of rolling elements included in the compressor bearing of the present invention.

The invention in the third embodiment or the fourth embodiment described above quenches at least one member of the inner ring, outer ring and a plurality of rolling elements for the carbonitriding process as shown in Fig. 2 or 3 described above, thereafter makes the temperature lower than A1 transformation temperature, and thereafter performs heating again and oil quenching so as to accomplish quenching. By this process, the compressor bearing member can have an average grain size of at most 6 μm of the austenite grain in the carbonitriding layer and a heat-affected portion.

The heat-affected portion refers to a material adjacent to the carbonitriding layer and the portion where the metal structure could be changed due to a thermal change in the carbonitriding process, quenching, cooling, tempering or the like.

"To provide an average grain size of at most 6 μm of the austenite grain" and "to provide a grain size number defined by JIS (Japanese Industrial Standards) of more than 10" provide respective austenite grain sizes almost identical to each other. In other words, from the structure of the austenite grain size showing the austenite grain size in Fig. 7 described hereinlater, it is determined that the austenite grain size of the conventional heat treatment bearing member is 10 in terms of the grain size defined by JIS (Japanese Industrial Standards). In contrast, the average grain size of the member of the invention is 5.6 μm, which corresponds to 12 in terms of the grain size number defined by JIS. Therefore, the grain size of the member of the invention is larger than

10 in terms of the grain size number defined by JIS.

By decreasing the austenite grain size, the rolling contact fatigue life can be improved remarkably. If the grain size number of the austenite grain size is not more than 10, the rolling contact fatigue life at a high temperature can be improved considerably. On the contrary, by employing the heat treatment method of the present invention, an austenite grain size exceeding 10 in terms of the grain size number can be obtained. The smaller the austenite grain size is, the longer the rolling contact fatigue life at a high temperature. For example, preferably the grain size number is at least 11. Usually, however, it is difficult to obtain a grain size number exceeding 13. It is noted that the austenite grain of the bearing component as described above does not change in a surface layer portion considerably affected by the carbonitriding process or an inner portion deeper than the surface layer portion.

Any member of the inner ring, outer ring and a plurality of rolling elements of the compressor bearing is a bearing component incorporated in the compressor bearing. The crack strength is improved in the case where the hydrogen content of the bearing component is in the above-described range, and the rolling contact fatigue life is improved in the case where the grain size number of the austenite grain is in the above-described range.

[7] As to the fracture stress value of at least 2650 MPa

In the following, a description will be given of a heat treatment method providing a fracture stress value of at least 2650 MPa of at least one member of the outer ring, inner ring and a plurality of rolling elements included in the compressor bearing of the present invention.

The invention of the fifth embodiment or the sixth embodiment described above quenches at least one member of the inner ring, outer ring and a plurality of rolling elements in order to perform the carbonitriding process as shown in Fig. 2 or Fig. 3 described above, thereafter makes the temperature lower than A1 transformation temperature, and thereafter performs heating again and oil quenching so as to

accomplish quenching. Through the process, the compressor bearing member can have a fracture stress value of at least 2650 MPa of the carbonitriding layer or the heat-affected portion of the compressor bearing member.

As described above, after the quenching for the carbonitriding process of the bearing component, the temperature is reduced to a temperature lower than A1 transformation temperature and thereafter the heating is performed again and the oil quenching is performed so as to accomplish the quenching. Accordingly, the steel having the carbonitriding layer can have a fracture stress value of at least 2650 MPa, which has not been obtained by the conventional art. In this way, a rolling bearing having an enhanced fracture stress value and a higher strength than the conventional ones can be obtained.

The above-described heat treatment can improve the crack strength and decrease the secular dimensional variation rate while carbonitriding the surface layer portion, as compared with the normal quenching performing quenching once directly after the carbonitriding process. As described above, the heat treatment method described above can provide a microstructure where the grain size of the austenite grain is less than a half that of the conventional one. The bearing component having undergone the heat treatment has a long rolling contact fatigue life, improved crack strength and reduced secular dimensional variation range.

[8] As to the austenite grain size (Figs. 4 and 5)

Fig. 4 is a diagram of a structure of the austenite grain size showing the austenite grain size of the bearing member heat-treated by the method of the invention shown in Fig. 2 or 3 and that of the bearing member heat-treated by the conventional method. In Fig. 4, (A) is a diagram of a structure of the austenite crystal grain size showing the austenite grain size of the bearing member heat-treated by the method of the present invention, and (B) is a diagram of a structure of the austenite grain size showing the austenite crystal grain size of the bearing member heat-treated by the conventional method for comparison.

Fig. 5 is a diagram showing the austenite grain size, illustrating in a diagrammatic form the structure of the austenite grain size showing the austenite grain size of the bearing member shown in Fig. 4.

In Fig. 5, (A) is a diagram illustrating in a diagrammatic form the structure of the austenite grain size in Fig. 4 (A), showing the austenite grain size of the bearing member heat-treated by the method of the present invention, and (B) is a diagram illustrating in a diagrammatic form the structure of the austenite grain size in Fig. 4 (B), showing the austenite grain size of the bearing member heat-treated by the conventional method for comparison.

From the structures of the crystal grain sizes of austenite showing the austenite grain size as described above, it is seen that the grain size of the conventional austenite grain is 10 which is a grain size number defined by JIS (Japanese Industrial Standards) while that of the present invention through the heat treatment thereof is 12 and thus fine grains are seen. Further, the average grain size Fig. 4 (A) is 5.6 μm measured by the intercept method.

[9] Manufacture procedure of each sample in Example 1

JIS-SUJ2 material (1.0 wt% of C - 0.25 wt% of Si - 0.4 wt% of Mn - 1.5 wt% of Cr) was used for making a comparison in mechanical properties of the bearing member heat-treated by the method of the present invention and the bearing member by the conventional heat treatment method. Samples shown in Table 1 were each produced through the procedure described below.

Table 1

Samples	A	B	C	D	E	F	Conventionally carbonitrided product	Normally quenched product
Secondary quenching temp.(°C)	780[1)]	800	815	830	850	870	-	-
Hydrogen content (ppm)	-	0.37	0.40	0.38	0.42	0.40	0.72	0.38
Grain size No. (JIS)	-	12	11.5	11	10	10	10	10
Charpy impact value (J/cm^2)	-	6.65	6.40	6.30	6.20	6.30	5.33	6.70
Fracture stress value (MPa)	-	2840	2780	2650	2650	2700	2330	2770
Rolling contact fatigue life ratio (L_{10})	-	5.4	4.2	3.5	2.9	2.8	3.1	1

1) Not evaluated this time due to insufficient quenching.

(1) (Samples A-D): Carbonitriding was performed at 850°C held for 150 minutes in an atmosphere of a mixture of RX gas and ammonia gas. Following the heat treatment pattern shown in Fig. 2 (or Fig. 3), primary quenching was done from a carbonitriding temperature of 850°C, and secondary quenching was subsequently done by heating to a temperature in a temperature range from 780°C to 830°C lower than the carbonitriding temperature. Sample A with a secondary quenching temperature of 780°C was not tested since quenching of sample A was insufficient.

(2) (Samples E and F): These samples were carbonitrided through the same

procedure as that of samples A-D of the present invention, and then secondary quenched at a temperature from 850°C to 870°C equal to or higher than the carbonitriding temperature of 850°C.

(3) (Conventional carbonitrided sample; comparative example): Carbonitriding was performed at 850°C held for 150 minutes in an atmosphere of a mixture of RX gas and ammonia gas. Quenching was successively done from the carbonitriding temperature and no secondary quenching was done.

(4) (Normal quenched sample; comparative example): Without carbonitriding, quenching was done by increasing the temperature to 850°C and no secondary quenching was done.

For the samples above, tests were conducted for (1) measuring the hydrogen content, (2) measuring the crystal grain size, (3) Charpy impact test, (4) measuring the fracture stress value and (5) the rolling fatigue test. Their results are shown in Table 1.

The results of the above-described measurements and tests will now be described.

(1) Hydrogen content

The conventional carbonitrided sample without being additionally processed has, as shown in Table 1, a considerably large hydrogen content that is 0.72 ppm. A reason therefor is considered that ammonia (NH_3) contained in the atmosphere in the carbonitriding process is decomposed and then hydrogen enters the steel.

In contrast, the hydrogen content of samples B-F is 0.37 to 0.42 ppm and thus almost a half of that of the conventional sample. This hydrogen content in the steel is equal in level to that of the normal quenched sample.

By reducing the hydrogen content in the steel and dissolving the hydrogen therein, the degree of embrittlement of the steel can be lessened. In other words, by reducing the hydrogen content, the Charpy impact value and the fracture stress value of samples B-F of the present invention could be remarkably improved.

(2) Crystal grain size

Regarding the crystal grain size, as shown in Table 1, samples that are secondary

quenched at a temperature lower than the temperature of quenching in the carbonitriding process (primary quenching), namely samples B-D have austenite grains which are remarkably made fine, i.e., crystal grain size number is 11 to 12. The four samples, namely samples E and F as well as the conventional carbonitrided sample and the normal quenched sample have austenite grains with the crystal grain size number of 10, which means that the crystal grain size of samples E and F is greater than that of samples B-D.

(3) Charpy impact value

Table 1 shows that the Charpy impact value of the conventional carbonitrided sample is 5.33 J/cm^2 while those of samples B-F of the present invention are higher, ranging from 6.20 to 6.65 J/cm^2. It is also seen from this that a lower secondary quenching temperature leads to a higher Charpy impact value. The normal quenched sample has a high Charpy impact value of 6.70 J/cm^2.

(4) Fracture stress value

The fracture stress value corresponds to anti-crack strength. It is seen from Table 1 that the fracture stress value of the conventional carbonitrided sample is 2330 MPa. In contrast, the fracture stress values of samples B-F are improved to 2650 to 2840 MPa. The normal quenched sample has a fracture stress of 2770 MPa which is substantially equal to that of samples B-F. It is considered that the reduction in hydrogen content greatly contributes to the improved anti-crack strength of samples B-F as well as the reduction in size of austenite grains.

(5) Rolling fatigue test

The normal quenched sample has the shortest rolling contact fatigue life L_{10} due to the absence of a nitriding layer in the surface layer. In contrast, the rolling contact fatigue life of the conventional carbonitrided sample is 3.1 times as long as that of the normal quenched sample. The rolling contact fatigue life of samples B-D is remarkably improved as compared with the conventional carbonitrided sample. Samples E and F have the rolling contact fatigue life almost equal to that of the conventional carbonitrided sample.

In summary, in samples B to F in the example of the invention, the hydrogen content in the steel is lower and the fracture stress value and the Charpy impact value are improved. However, if the improvements are to be made including the improvement of the rolling contact fatigue life, samples B to D are made finer with the grain size number of the austenite grain size of approximately 11 or larger.

Samples B to F correspond to examples of the present invention, however, a more desirable scope of the present invention is samples B to D having grains made further finer by making the secondary quenching temperature lower than the carbonitriding process temperature.

[10] Manufacture procedure of each sample in Example 2

On samples X, Y and Z described below, a series of tests were performed. JIS-SUJ2 material (1.0 wt% of C - 0.25 wt% of Si - 0.4 wt% of Mn - 1.5 wt% of Cr) was used as a material to be heat treatment, which is common to samples X to Z. Samples X to Z were manufactured through the following procedure.

(Sample X: comparative example): normal quenching only without carbonitriding

(Sample Y: comparative example): conventional carbonitriding and quenching method for comparison, quenching directly after carbonitriding in an atmosphere of a gas mixture of RX gas and ammonia gas, the temperature of the carbonitriding process was 845°C and the held time was 150 minutes.

(Sample Z: example of the present invention): the heat treatment pattern in Fig. 2 was applied to a bearing steel. The atmosphere was a gas mixture of RX gas and ammonia gas, the carbonitriding process temperature was 845°C, the held time was 150 minutes and the final quenching temperature was 800°C.

(1) Rolling contact fatigue life

Using the rolling contact fatigue life test in Fig. 7 described above, the rolling contact fatigue life test was conducted under the test conditions shown in Table 2. The results are shown in Table 3.

Table 2

Test piece	ϕ 12×L22 cylindrical test piece
Number of tested pieces	10
Counterpart steel ball	3/4" (19.05 mm)
Contact surface pressure	5.88 Gpa
Load speed	46240 cpm
Lubricating oil	Turbine VG68 - forced circulation lubrication

Table 3

Sample	Life (load count)		Relative L_{10}
	L_{10} ($\times 10^4$ times)	L_{10} ($\times 10^4$ times)	
X	8017	18648	1.0
Y	24656	33974	3.1
Z	43244	69031	5.4

Sample Y of the comparative example has, as shown in Table 3, L10 life (the life where one out of ten test pieces being damaged) that is 3.1 times as long as the L10 life of sample X which undergoes normal quenching only, and thus it is seen that the effect of extending the life is obtained through the carbonitriding process. In contrast, sample Z of an example of the present invention has a longer life which is 1.74 times as long as that of sample Y and 5.4 times as long as that of sample X. It is considered that this improvement is obtained mainly from the fine microstructure.

(2) Charpy impact test

A Charpy impact test was conducted by using a U-notch test piece defined by JIS Z 2242 mentioned above. Test results are shown in Table 4.

Table 4

Sample	Charpy impact value (J/cm^2)	Relative impact value
X	6.7	1.0
Y	5.3	0.8
Z	6.7	1.0

Sample Z of the example of the present invention achieved a Charpy impact value substantially equal to that of sample X (comparative example) having undergone only normal quenching and higher than that of carbonitrided sample Y (comparative example).

(3) Static fracture toughness test

In a test piece for a static fracture toughness test, a pre-crack of approximately 1 mm was made, thereafter a static load P by three-point bending was added, and then a fracture load was determined. Using the following formula, a fracture toughness value (KIC value) was calculated. Results of the test are shown in Table 5.

$$KIC = (PL \sqrt{a}/BW2) \{5.8 - 9.2 (a/W) + 43.6 (a/W)^2 - 75.3 (a/W)^3 + 77.5 (a/W)^4\}$$

Table 5

Sample	Number tested	K_1C ($MPa\sqrt{m}$)	Relative K_1C
X	3	16.3	1.0
Y	3	16.1	1.0
Z	3	18.9	1.2

As the previously introduced crack has a depth greater than the depth of the

nitriding layer, the same results are obtained for samples X and Y that are comparative examples, while sample Z that is the example of the present invention achieves a fracture toughness value (KIC value) approximately 1.2 times as high as those of samples X and Y that are comparative examples.

(4) Static-pressure fracture-strength test (measurement of fracture stress)

On a static-pressure fracture-strength test piece, a load was exerted to conduct a static-pressure fracture-strength test. Test results are shown in Table 6.

Table 6

Sample	Number tested	Static fracture strength (kgf)	Relative static fracture strength
X	3	4200	1.00
Y	3	3500	0.84
Z	3	4300	1.03

Carbonitrided sample Y (comparative example) has a value of the static-pressure fracture-strength slightly smaller than that of sample X (comparative example) having been subjected to normal quenching alone. In contrast, sample Z of the example of the present invention has a static-pressure fracture-strength value higher than that of sample Y and slightly higher than that of sample X.

(5) Rate of secular dimensional variation

The rate of secular dimensional variation was measured under the conditions of 130°C and a holding time of 500 hours. The result of the measurement is shown in Table 7, together with the surface hardness and the amount of retained austenite (at 0.1 mm depth from the surface).

Table 7

Sample	Number tested	Surface hardness (HRC)	Retained γ (vol.%)	Rate of dimensional change ($\times 10^{-5}$)	Relative rate of dimensional change*)
X	3	62.5	9.0	18	1.0
Y	3	63.6	28.0	35	1.9
Z	3	60.0	11.3	22	1.2

* : smaller is superior

As compared with the rate of dimensional variation of sample Y having a large amount of retained austenite, sample Z of the example of the present invention has a lower rate of dimensional variation.

(6) Life test under contaminated lubricant condition

Ball bearing 6206 was used to evaluate the rolling contact fatigue life under a contaminated lubricant condition having a predetermined amount of normal contaminants mixed therein. Test conditions are shown in Table 8 and test results are shown in Table 9.

Table 8

Load	Fr = 6.86 kN
Contact surface pressure	Pmax = 3.2 Gpa
Rate of rotation	2000 rpm
Lubricant	Turbine 56 - oil bath lubrication
Amount of contaminant	0.4g/1000cc
Contaminant	Grain size: 100-180 μ m, hardness: Hv800

Table 9

Sample	L_{10} life (h)	Relative L_{10}
X	20.0	1.0
Y	50.2	2.5
Z	45.8	2.3

Sample Y (comparative example) having undergone carbonitriding has a lifetime which is approximately 3.7 times as long as that of sample X, and sample Z of the example of the present invention has a lifetime which is approximately 3.7 times as long as that of sample X. While sample Z of the example of the present invention has a smaller amount of retained austenite than that of sample Y of the comparative example, sample Z has a lifetime equal to or longer than that of sample Y because of influences of entering nitrogen and the fine microstructure.

It is accordingly seen from the above-discussed results that, sample Z of the .example of the present invention, namely a bearing component produced by the heat treatment method of the present invention can simultaneously achieve three goals: extension of the rolling contact fatigue life that has been difficult to achieve by the conventional carbonitriding, improvement in crack strength and reduction of the rate of secular dimensional variation.

[11] Modified Application

(1) Compressor bearing including a pulley mechanism

Fig. 10 is a schematic cross section of a compressor including a compressor pulley mechanism having a compressor bearing using another pulley mechanism. In the drawing, as main support bearing 402, the deep groove ball bearing as shown in Fig. 6 (A) is used. As pulley support bearing 403, the multiple-row angular contact ball bearing as shown in Fig. 6 (B) is used. The compressor bearing is not limited to the examples, and any bearing appropriate for the purpose may be used.

(2) Pulley mechanism

As the compressor pulley mechanism, other than pulley mechanism 400 in Fig. 1 described above, another pulley mechanism such as pulley mechanism 400 in Fig. 10 may be used. In pulley mechanism 400 in Fig. 10, main shaft support bearing 402 and pulley support bearing 403 are incorporated like pulley mechanism 400 in Fig. 1. Further, although pulley mechanism 400 in Figs. 1 and 10 includes clutch electromagnet 419, a pulley mechanism without a clutch electromagnet may be used.

(3) Compressor

Although the description is given of the compressor bearing applied to the single swash plate-type swash plate compressor for car air-conditioner of compressor 100 in Fig. 1 described above, the present invention is not limited thereto. The other type of swash plate compressor or a scroll-type compressor may be used. The other type of swash plate compressor includes, for example, a double swash plate-type swash plate compressor, a single swash plate-type variable-displacement swash plate compressor, and the like.

The embodiments and examples disclosed herein are to be construed as given for illustration in all respects, not for limitation. It is intended that the scope of the invention is not given by the description above but by the claims, and includes all modifications equivalent in meaning and scope to the claims.

[Effects of the Invention]

The compressor bearing of the present invention may not have all of the effects of the invention as described below simultaneously. The bearing may have at least one effect of the invention.

The conventional art provides a hydrogen content exceeding 0.5 ppm. Therefore, the steel becomes brittle and the crack strength deteriorates, and thus it is inappropriate for use in a portion where a severe load is exerted. However, the hydrogen content of at most 0.5 ppm may be used to improve the crack strength.

Further, the conventional art has a difficulty in improving the anti-crack strength due to coarsened austenite grain. However, an average grain size of the austenite grain

of at most 6 μm may be provided so that the rate of secular dimensional variation is reduced due to an increased amount of retained austenite.

Furthermore, the conventional art has a difficulty in obtaining a material having a special alloy component in the composition in order to provide a long life against the rolling fatigue, improved crack strength and suppressed increase of the rate of secular dimensional variation, and the material cost is high. However, the fracture stress value of at least 2650 MPa may be provided to increase the fracture stress value and improve the anti-crack strength as compared with the conventional art.

Using the bearing material heat-treated as described above, (1) a long life against the rolling fatigue can be secured, (2) the crack strength can be improved and (3) an increase of the rate of secular dimensional variation can be suppressed.

[Brief Description of the Drawings]

Fig. 1 is a schematic cross section of a pulley mechanism of a single swash-plate-type swash plate compressor 200 and a compressor pulley mechanism 400.

Fig. 2 is a diagram of a first heat treatment pattern performing primary quenching for a compressor bearing of the present invention, thereafter reducing the temperature by oil quenching to a temperature considerably lower than the A1 transformation temperature, and then performing secondary quenching.

Fig. 3 is a diagram of a second heat treatment pattern performing quenching for a carbonitriding process of the compressor bearing of the present invention, then heating again when the temperature becomes lower than the A1 transformation temperature, and thereafter oil quenching to perform quenching.

Fig. 4 is a diagram of the austenite grain size showing the austenite grain size of a bearing member heat-treated by the method of the invention show in Fig. 3 and a bearing member heat-treated by the conventional method.

Fig. 5 is a diagram of the austenite grain size showing the austenite grain size diagrammatically showing an austenite grain size structure showing the austenite grain size of the bearing member shown in Fig. 4.

Fig. 6 is a cross section showing a deep groove ball bearing and a multiple-row angular ball bearing.

Fig. 7 is a cross section showing a cylindrical roller bearing.

Fig. 8 is a cross section showing a four-point contact ball bearing.

Fig. 9 is a cross section showing a needle roller thrust bearing.

Fig. 10 is a schematic cross section of a compressor including a pulley mechanism having a compressor bearing using another pulley mechanism.

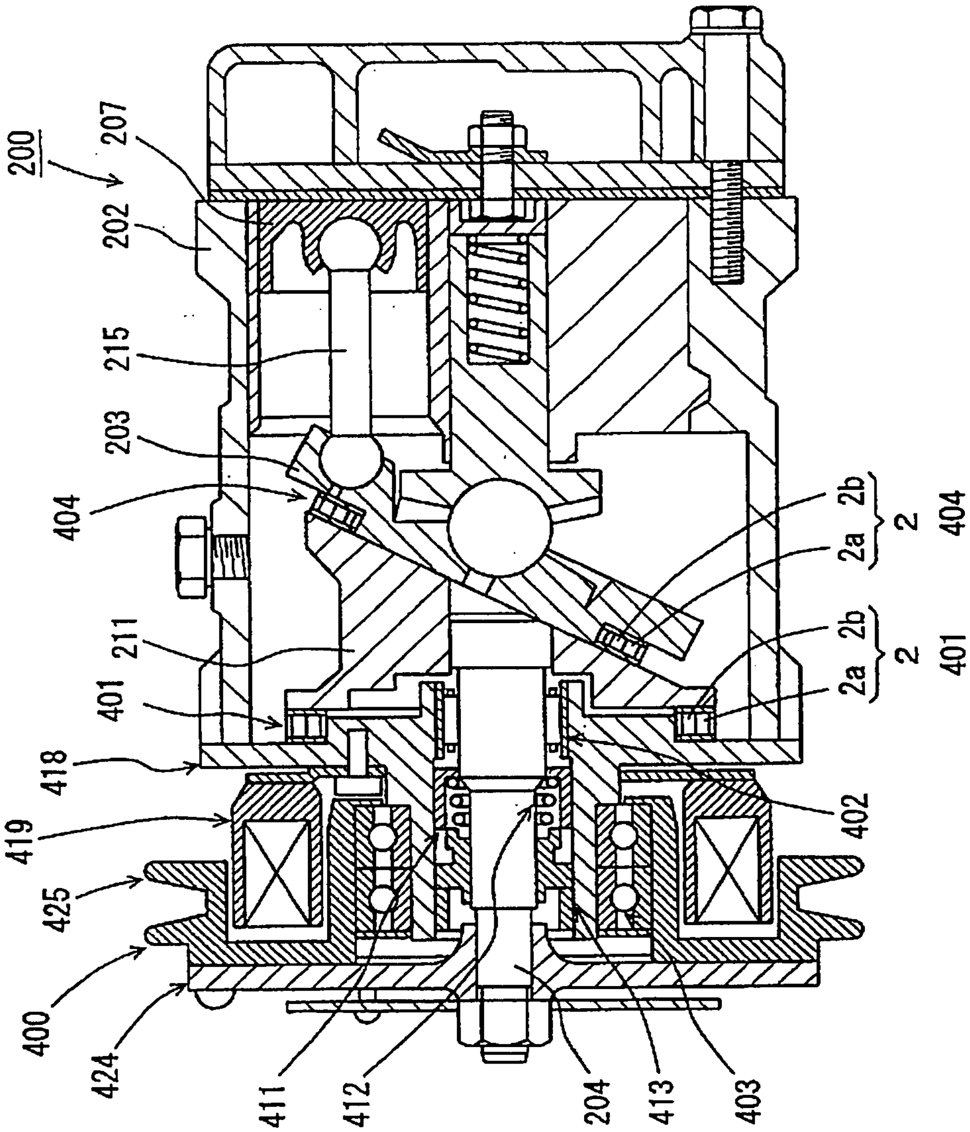
[Description of the Reference Characters]

200 compressor (body), 2 needle roller, 2a outer diameter-side needle roller, 2b inner diameter-side needle roller, 3 upper retainer, 4 lower retainer, 31 outer ring, 32 inner ring, 33 a plurality of cylindrical rolling elements, 34 retainer, 103 multiple-row radial bearing, 104 radial bearing, 202 housing, 203 swash plate, 204 main shaft, 211 rolling member, 207 piston, 215 piston rod, 400 compressor pulley mechanism, 401 rolling member/pulley support member bearing, 402 main shaft support bearing, 403 pulley support bearing, 404 swash plate support bearing, 411 spring receiving member, 412 spring, 413 string slide member, 418 pulley bearing support member, 419 clutch electromagnet, 424 power transmitting member, 425 pulley

【書類名】　図面 drawings
document name

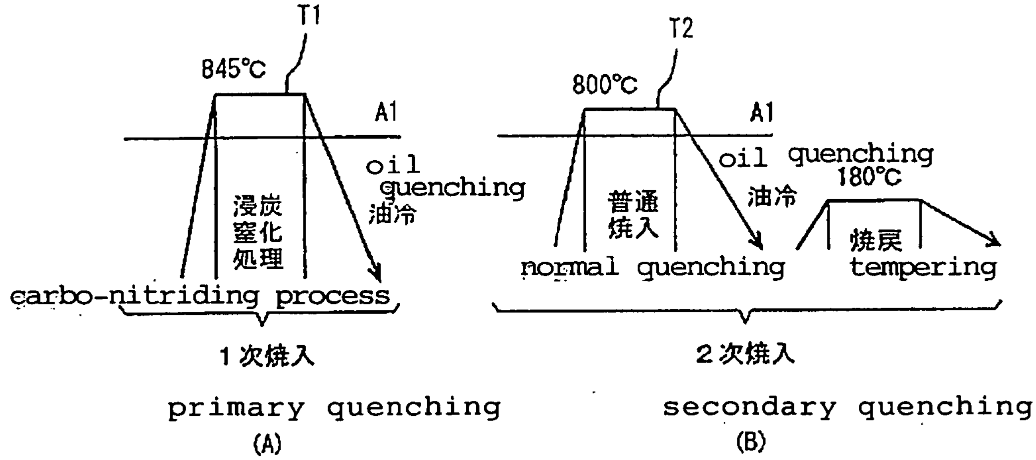
【図１】

Fig. 1



【図２】

Fig. 2



【図３】

Fig. 3

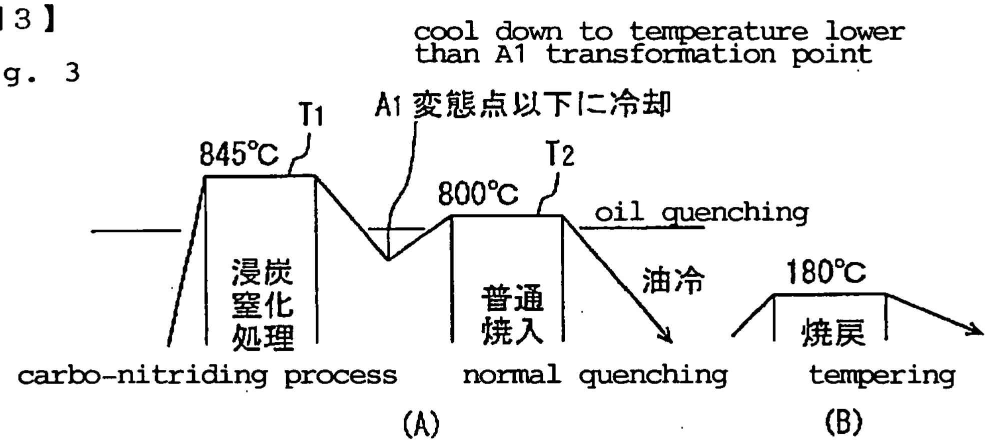


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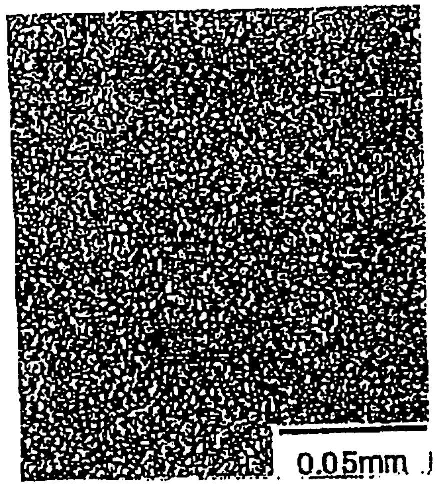
Fig. 4



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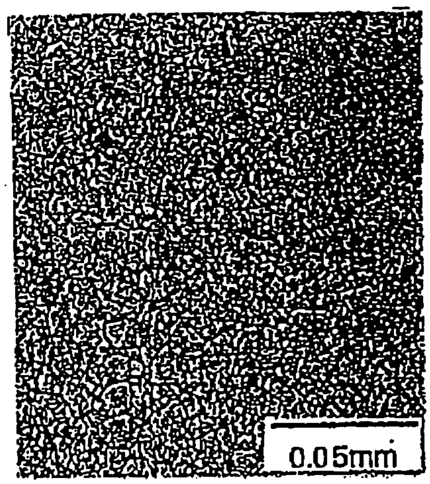

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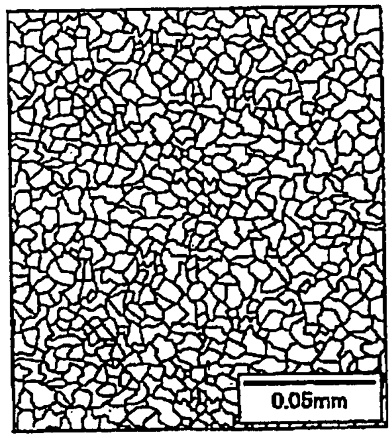
【図５】

Fig. 5



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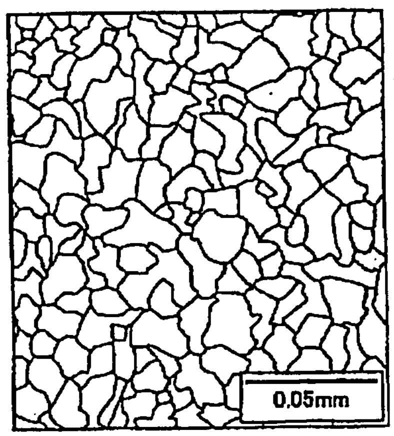

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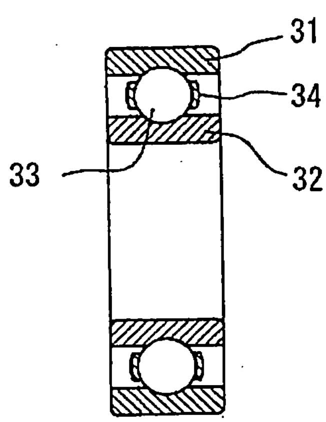
【図６】

Fig. 6



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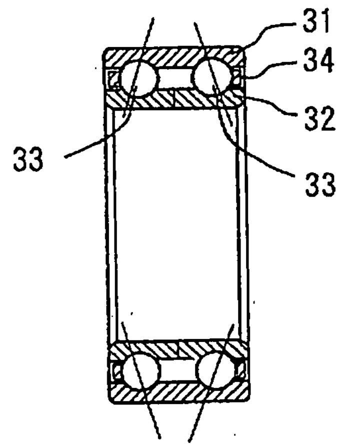
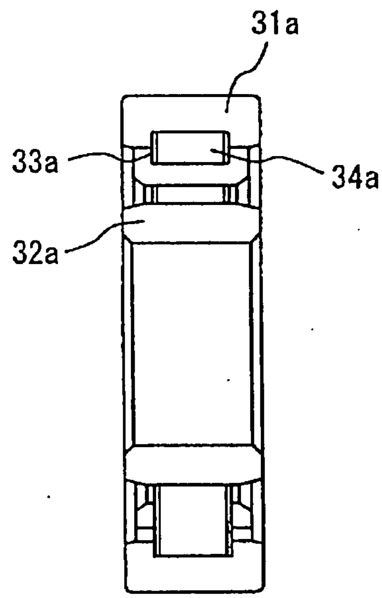
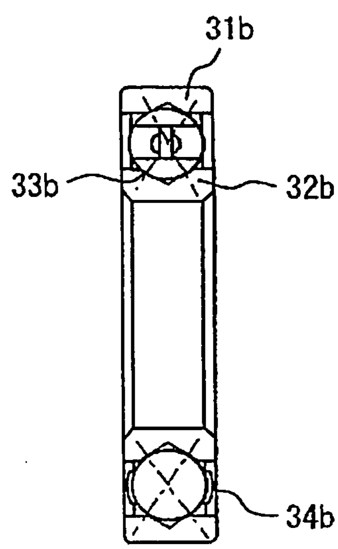


(B)

【図７】
Fig. 7

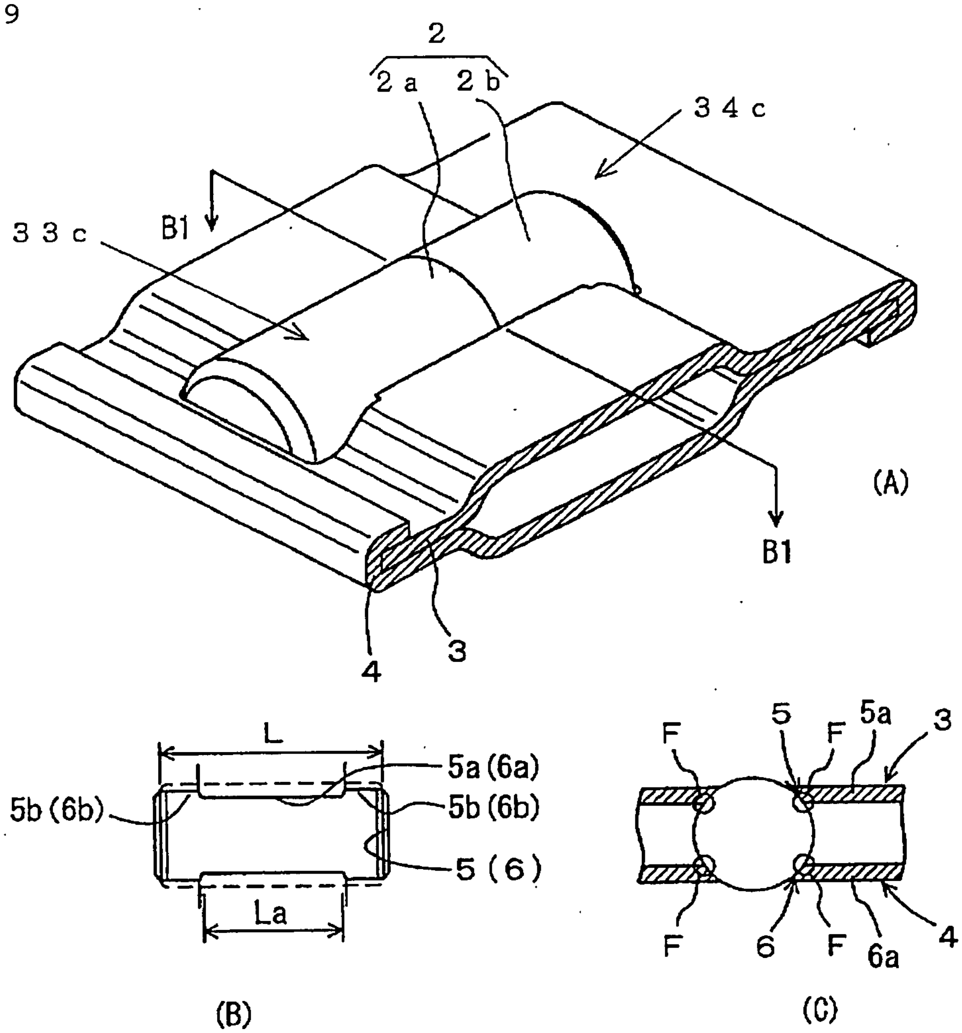


【図８】
Fig. 8



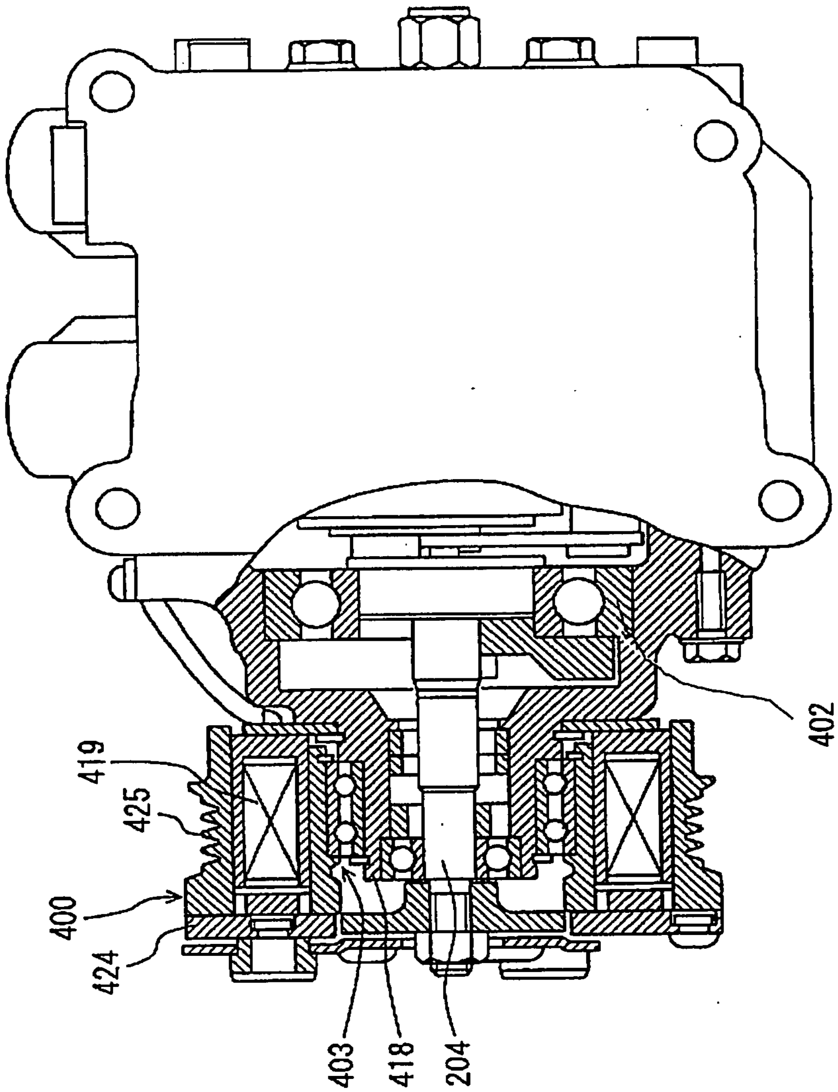
【図９】

Fig. 9



【図１０】

Fig. 10



[Document Name] Abstract

[Abstract]

[Subject] A compressor bearing is provided having a long rolling contact fatigue life, a high anti-crack strength and a reduced rate of secular dimensional variation.

[Solving Means] In compressor bearings 401, 402, 403 and 404 used for a compressor body 200 and a compressor pulley mechanism 400 transmitting a driving force to the compressor body, at least one member of an outer ring, an inner ring and a plurality of rolling elements included in the compressor bearing has a hydrogen content of at most 0.5 ppm, a grain size number of an austenite grain in a range exceeding 10, or a fracture stress value of at least 2650 MPa.

[Selected Drawing] Fig. 1